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Adaptability and yield performance of taro (*Colocasia esculenta* (L.) Schott) cultivars in three agro-ecological zones in Ghana

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ABSTRACT

Low yields of taro (*Colocasia esculenta* (L.) Schott) reported in Ghana are due to inadequate agricultural techniques and research. To explain the reported yields under these conditions, it is necessary to understand how various soils and climatic factors affect the growth and development of these new varieties when selecting appropriate genotypes for diverse agro-ecological environments. **Four cultivars of taro namely;** Huogbelor, Asempa, Agyenkwa and Y'anyawoa were, evaluated for their adaptability and yield performance in the rain forest, semi-deciduous forest and forest-savannah transition zones in Ghana in a Randomized Complete Block Design (RCBD) with three replications. Analysis of variance showed significant ($P < 0.05$) differences among the agro-ecological zones in terms of the vegetative growth, number of suckers/stand and inflorescence numbers of taro but not for corm yield. Taro cultivars also differed significantly ($P < 0.05$) in terms of the number of leaves/stand but were statistically similar ($P > 0.05$) for number of suckers. Number of inflorescences differed significantly ($P < 0.05$) among the agro-ecological zones, cultivars as well as their interactions. The results also revealed significant ($P < 0.05$) agro-ecological zone and cultivar interactions for taro growth and yield. The Coastal-savannah translated the high vegetative growth of Hougbelor into corm yield of 25.67 tons/ha while the Agyenkwa cultivar produced higher numbers of suckers (25.0) and inflorescences (2.43) in the same agro-ecological zone.

1. Introduction

Taro (*Colocasia esculenta* (L.) Schott) was previously believed to be an ancient Southeast Asian food crop with unknown genetic and geographical origins [1–3]. However, a recent study by Ahmed et al. [4] has revealed that cultivated taro is polyphyletic, having tropical and temperate clades that seem to have their origins in Southeast Asia Sensu lato. A third clade was also found among wild populations from Southeast Asia to Australia and Papua New Guinea [4]. It is a perennial herbaceous crop that is often cultivated as an annual crop [5,6]. Taro has been ranked 14th amongst the major vegetable crops in the world. It is produced on 1.8 million hectares of land worldwide with global and average yields of 9.2 million tonnes and 5.1 t/ha respectively [7]. In Asia, Africa, Papua New Guinea and the Pacific Islands, taro is mostly cultivated for household consumption. Taro is most popular in the Pacific Islands, where it is known for its cultural, gastronomic and economic values. It is regarded as a key component of every meal in many Pacific Island countries. West Africa produces the highest taro yields [8]. It is also a popular export item in several countries, including Fiji and the Cook Islands and it used to be in Samoa before to 1993 [9]. In Africa, the crop contributes to food security and has other economic and socio-cultural importance [10–12].

Taro is considered one of the lowest yielding root crops in the world [13]. This may be due to infestation by pests and diseases such as taro leaf blight (TLB) disease [14]. Weeds, inadequate labor, land scarcity, inadequate planting material, lack of better varieties, ineffective marketing, restricted research, and limited extension services are among several other limitations to taro production [2]. The crop was previously neglected and underutilized [15]. With an annual yield of over 1,460, 938 tonnes, Ghana has been ranked as the world's third largest producer of taro, accounting for roughly 14% of the global output and 19% of the production in Africa. Commercial yields in Ghana are still considered to be low. Between 2015 and 2017 for instance, taro yield in Ghana dropped from 7.1 t/ha to 6.2 t/ha [16]. This has been attributed to

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inadequate agricultural techniques, limited research and underutilization of the crop. Plant population, plant spacing and planting materials are all aspects of Ghanaian taro that have not been well studied [17]. According to WAAPP-Ghana, the average yearly growth rate of taro yield has declined by 3.4% since 2005. The constraints of taro production in Ghana may however, be addressed and if feasible, resolved through research.

In recent years, several studies have evaluated the performance of various crop genotypes in several ecological zones of Ghana. To explain the commercial yields reported under these conditions, it is necessary to have an extensive understanding of the effects of various soils and climatic factors on the growth and development of new crop varieties in diverse agro-ecological environments. In this study, it was hypothesized that a highly productive taro genotype is likely to be highly adaptive to a specific agro-ecological zone for commercial production and increased utilization. The study therefore aimed at evaluating the performance of four taro cultivars, locally known as Huogbelor, Asempa, Agyenkwa and Y'anyawoa [18] in the rain forest, semi-deciduous forest and forest-savannah transition zones in Ghana in a single trial experiment. The local names Asempa, Agyenkwa and Y'anyawoa originated from the Ghanaian Twi dialect. These cultivars were introduced into Ghana from the Pacific by the Crop Research Institute of the Council for Scientific and Industrial Research (CSIR-CRI) located at Fumesua in Kumasi in the Ashanti Region of Ghana, and were developed by the International Network for Edible Aroids (INEA). The cultivars have proven to be tolerant to the TLB disease and have the potential to produce between 12 and 25 tonnes per hectare and corm dry matter content of 33–42% [18].

2. Materials and methods

2.1. The study areas

The Coastal savannah, Forest-savannah, and Semi-deciduous zones in the Western, Bono, and Ashanti Areas, respectively, were studied in the perspective of a cross-regional study that spanned three agro-ecological zones occurring in parts of three taro-producing regions in Ghana. A multi-locational field experiment was specifically conducted at the Kwadaso Agricultural College research site, University of Energy and Natural Resources, Dormaa campus research site and Beahu in the Kumasi Metropolitan, Dormaa Municipal and Ahanta West district of the Ashanti, Western and Bono regions of Ghana respectively. The edaphic descriptions of the study areas are presented in Table 1.

Table 1
Physical and chemical properties of soils in Study areas/Agro-Ecological Zones.

Parameter	Agro-Ecological Zone		
	Coastal-savannah	Forest-savannah	Semi-Deciduous
Sand (%)	82.00	78.00	74.00
Silt (%)	10.00	16.00	16.00
Clay (%)	8.00	6.00	10.00
pH (1:2.5 H_2O)	5.3	5.5	6.2
Organic C (%)	1.84	2.15	1.92
Total Nitrogen (%)	0.13	0.19	0.18
OM (%)	3.16	3.71	3.30
Ca^{2+}/100g	1.28	1.31	1.40
Mg^{2+}/100g	0.43	0.21	0.64
K^{+}/100g	0.07	0.03	0.06
Na^{+}/100g	0.04	0.03	0.06
Total Exchangeable Base (me/100g)	1.82	1.58	2.16
Exchangeable Acidity Al + H (me/100g)	0.60	0.50	0.15
Effective Cationic Exchange Capacity (me/100g)	2.42	2.08	2.31
Base Saturation (%)	75.25	75.94	93.50
P (mg/kg)	20.02	17.94	8.81
Texture	Loamy sand	Loamy sand	Sandy loam

Source: Council for Scientific and Industrial Research-Soil Research Institute, Kwadaso-Kumasi.

2.1.1. Ahanta West Municipal

The Ahanta West Municipal District, with its headquarters in Agona Nkwanta, is located near the southernmost part of the country and the whole West African Sub-Region. To the east lies the Sekondi-Takoradi Metropolitan Assembly (STMA), to the west is the Nzema East Municipal, to the north is the Mpohor Wassa East District, and to the south is the Gulf of Guinea. The district lies in the equatorial climatic zone of Ghana's south-western region. The highest average temperature is 34 °C, which occurs between March and April, while the lowest average temperature is 20 °C, which occurs in August. During the rainy season, relative humidity ranges from 75 to 85%, while during the dry season, it ranges from 70 to 80%. The district is situated in Ghana's wettest region. It has a double maximum rainfall of more than 1700 mm. The rainy season lasts from April through September, with the most rainfall falling between April and July [19]. Fig. 1 shows the map of the Ahanta West Municipal.

2.1.2. Kumasi Metropolitan

The Kumasi Metropolis is 250–300 m above sea level and is between Latitude 6.35 ^{O}N and 6.40 ^{O}S and Longitude 1.30 ^{O}W and 1.35 ^{O}E. The Metropolis is bordered on the north by Kwabre East and Afigya Kwabre Districts, on the west by Atwima Kwanwoma and Atwima Nwabiagya Districts, on the east by Asokore Mampong and Ejisu-Juaben Municipality, and on the south by Bosomtwe District. The climate of the Metropolis is considered as wet sub-equatorial. The average lowest temperature is approximately 21.5 ^{O}C, with a high temperature of around 30.7 ^{O}C. At sunrise and dusk, the average humidity is around 84.16% and 60%, respectively. It features a rainfall regime with two maximums (214.3 mm in June and 165.2 mm in September). The Metropolis is located in a transitional forest zone, notably the moist semi-deciduous South-East Ecological Zone [20]. Fig. 2 shows the map of Kumasi metropolitan.

2.1.3. Dormaa Municipal

The Dormaa municipality is situated at the western part of the Brong Ahafo Region. It lies within longitudes 3.00 ^{O}W and 3.30 ^{O}E and latitudes 7.00 ^{O}N and 7.30 ^{O}S. It is bordered on the north by the Jaman South district and on the east by the Dormaa East district, on the south and south-east by the Asunafo and Asutifi districts, on the west and south-west by Dormaa West, and on the west and north-west by La Côte d'Ivoire. The municipal capital, Dormaa Ahenkro, is about 80 km west of Sunyani, the regional capital. The highest point in the area is more than 375 m above sea level. The municipality has a humid semi-arid climate with a double maximum rainfall regime. Rainfall varies between 125 and 175 mm annually. The first rainy season runs from May to June, while the second rainy season is from September to October. The dry season is extremely distinct, with the primary one starting in late November and ending in February. Relative humidity ranges from 75 to 80% in the rainy seasons and from 70 to 72% during the rest of the year. Between March and April, the greatest mean temperature is around 30 ^{O}C, and between August and September, the lowest is about 26.1^{O}C. Semi-Equatorial woodland, semi-deciduous forest, and high grassland are the three principal vegetation types found here [21]. Fig. 3 shows the map of Dormaa Municipal.

2.1.4. Experimental design and measurements

Treatments for the multi-locational experiments were arranged in a Randomized Complete Block Design (RCBD) with three replications. Four cultivars of taro known as Huogbelor (C_1), Asempa (C_2), Agyenkwa (C_3) and Y'anyawoa (C_4) were grown in the Semi-deciduous rainforest (Z_1), Coastal savannah (Z_2) and Forest-savannah transition (Z_3) agro-ecological zones occurring in parts of the Ashanti, Western and Bono regions of Ghana, respectively. The multilocational experiments

Fig. 1. Map of ahanta west municipal.

Fig. 2. Map of kumasi metropolitan.

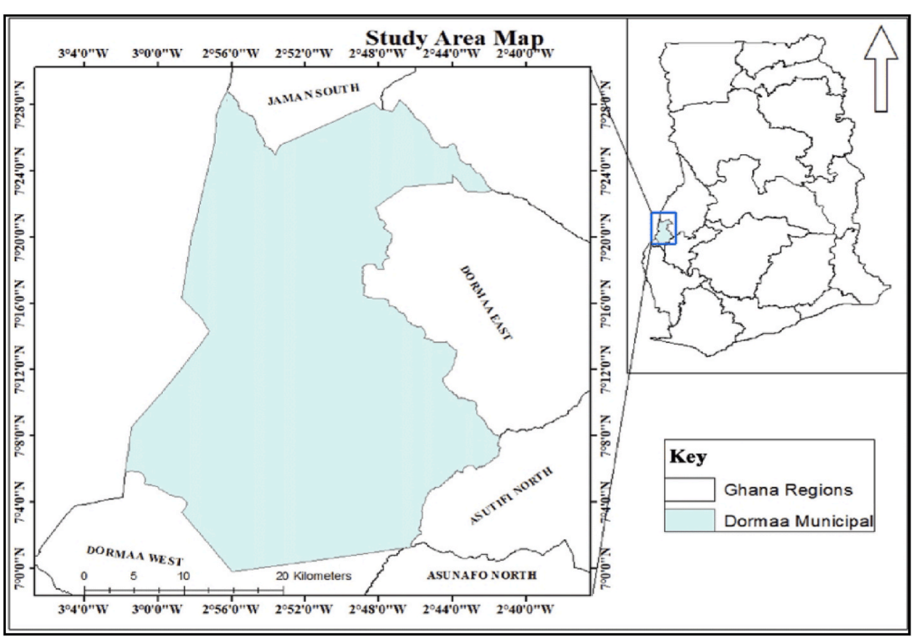

Fig. 3. Map of dormaa municipal.

consisted of four blocks and three plots, with 1 m distance between blocks. Each plot measured 6 m × 2 m with 1 m distance between plots. Each block measured 6 m × 8 m, giving a total of 36 plots in the three agro-ecological zones and a total land area of 216 m^2 (27 m × 8 m) in each agro-ecological zone.

Weeds and stumps were cleared off the experimental sites. The sites were then pegged and lined to be demarcated into blocks and plots. Planting materials for the experiments were sourced from the CSIR-CRI. Twenty-seven transplants were obtained for each cultivar, resulting in a total of 108 transplants. Planting was done three days after land preparation and late in the evening at a spacing of 1 m × 1 m. Three transplants were planted on each replicated plot. The experimental plots were watered soon after transplanting.

Weeds in the experimental plots were controlled using cutlass. Weeding was carried out two weeks after transplanting and repeated every fortnight for eight weeks. Initial soil data were collected from the experimental fields. A composite soil sample was taken from 16 different spots across the fields using a core sampler from a depth of 0–15 cm. They were air-dried for four days and passed through a 2 mm sieve to remove large particles, debris and stones. The samples were analyzed at the laboratory of the Soil Research Institute of the Council for Scientific and Industrial Research (CSIR-SRI) at Kwadaso in Kumasi for their chemical and physical composition (Table 1).

2.1.5. Growth data

Vegetative growth of the cultivars was measured as height of parent plant and number of leaves per stand. The height from the base of the stem to the topmost growing point of parent plants in each plot were measured using a meter rule at two weeks intervals starting from three weeks after transplanting (WAT) for eight weeks. Leaves/stand for the three stands in each plot was also counted at two weeks intervals starting from three WAT for eight weeks. Average plant height and number of leaves were estimated for each plot.

2.1.6. Reproductive and yield data

The suckers produced by each parent plant in each plot were counted fortnightly from 11 to 14 WAT. The flowers produced by each stand were also counted as they appeared and averages estimated for each plot. Harvesting was done on 25th December 2020 (32 weeks after transplanting) during which yield data were collected. Corm weight/stand was measured by weighing the corms harvested from each plot together using a weighing balance. Corm weight/stand for the entire plot was used to estimate corm yield per hectare as follows:

$$\text{Total Plot Area} = 12\ \text{m}^2 : \text{X kg} \tag{1}$$

$$\text{Total Area per hectare} = 10,000\ \text{m}^2 : \text{Y kg} \tag{2}$$

$$\text{Then, total corm weight per hectare, Y} = \frac{10000m^2 x\ corm\ weigt/plot}{12m^2} \tag{3}$$

$$\text{Total corm yield} \Big/ \text{ha (tons / ha)} = \frac{total\ corm\ weight/ha}{1000} \tag{4}$$

Where X = corm weight/plot and Y = total corm weight/ha.

2.2. Statistical analysis

Data from the field experiments were subjected to a two-way analysis of variance using GenStat statistical software, 11th edition with taro cultivars and agro-ecological zones as factors. The least significant difference (LSD) criterion was applied to distinguish means that significantly ($P < 0.05$) differed among treatments. Mean differences larger than the LSD were considered as significant, and otherwise not significant.

3. Results

3.1. Growth parameters

3.1.1. Number of leaves/stand

Results of number of leaves/stand are presented in Table 2. Significant ($P < 0.05$) differences were observed among the agro-ecological zones for number of leaves/stand at all sampling periods. At 3 and 5 WAT, the number of leaves from the Forest-savannah and the Semi-deciduous zones were statistically similar ($P > 0.05$) but differed significantly ($P < 0.05$) for the Coastal-savannah zone. Number of leaves for the Coastal-savannah and Semi-deciduous zones were not significantly ($P > 0.05$) different but both differed significantly ($P < 0.05$) from the Forest-savannah zone at 7, 9, 11 and 13 WAT. At 15 and 17 WAT, number of leaves/stand was significantly ($P < 0.05$) different in all the agro-ecological zones. The Coastal-savannah zone recorded the highest mean number of leaves/stand (3.2, 4.1, 4.8 and 6.8 at 3, 5, 7 and 9 WAT respectively), whereas the Semi-deciduous zone recorded the highest at 11, 13, 15 and 17 WAT. The Forest-savannah zone recorded the lowest mean number of leaves/stand for all the sampling periods (1.5, 2.7, 3.2, 4.5, 5.6, 6.4, 6.6 and 7.4 at 3, 5, 7, 9, 11, 13, 15 and 17 WAT respectively).

Significant ($P < 0.05$) differences were observed amongst the cultivars for number of leaves/stand at 11, 13, 15 and 17 WAT. Hougbelor produced the highest number of leaves/stand at all sampling periods except at 17 WAT where the highest mean number of leaves/stand was recorded for Agyenkwa, with Asempa producing the least at 7, 9, 11, 13, 15 and 17 WAT.

The 'agro-ecological zone' by 'cultivar' interactions for number of leaves/stand differed significantly ($P < 0.05$) at all sampling periods. The highest number of leaves/stand for the first two sampling periods were recorded for Hougbelor grown in the Coastal-savannah zone, whereas Agyenkwa and Hougbelor grown in the Coastal-savannah zone recorded the highest at the 3rd and 4th sampling periods, respectively, whilst Hougbelor recorded the highest in the Semi-deciduous zone during the last four sampling periods. Agyenkwa produced the lowest number of leaves/stand in the Semi-deciduous zone during the first four sampling periods whereas Asempa produced the lowest in the Forest-savannah zone during the last five sampling periods.

3.1.2. Height of parent plant

Results on the height of parent plant are presented in Table 3. There were significant ($P < 0.05$) differences among the agro-ecological zones at all sampling periods except for the 2nd sampling period. At 3 WAT, height of parent plant in the Forest-savannah and Semi-deciduous zones differed significantly ($P < 0.05$) but both were statistically similar to the Coastal-savannah zone. At 7, 9 and 11 WAT, the Coastal-savannah and Semi-deciduous zones recorded significantly ($P < 0.05$) different height of parent plant but were not significantly ($P > 0.05$) different from the Forest-savannah zone. At 13 WAT, height of parent plant at the Forest-savannah and Semi-deciduous zones were statistically similar but were significantly ($P < 0.05$) different from the Coastal-savannah zone. At 15 WAT, height of parent plant differed significantly ($P < 0.05$) in all the agro-ecological zones. The Coastal-savannah and Forest-savannah zones were at par ($P > 0.05$) at 17 WAT but both differed significantly ($P < 0.05$) from the Semi-deciduous zone for height of parent plant. The Forest-savannah zone recorded the tallest parent plants during the first two sampling periods (51.81 and 57.73 cm at 3 and 5 WAT respectively) whilst the Semi-deciduous zone recorded the tallest plants for the rest of the sampling periods (66.03, 75.28, 85.00, 102.74, 115.52 and 127.30 cm at 7, 9, 11, 13, 15 and 17 WAT respectively).

No significant ($P > 0.05$) difference was recorded among the cultivars in terms of height of parent plant for all sampling periods. However, Agyenkwa recorded the tallest parent plants at the first three sampling periods (50.16, 57.11 and 63.86 cm respectively). At 9 and 11 WAT Asempa recorded the highest plant height (72.07 and 78.89 cm

Table 2
Number of leaves/stand of taro grown in three Agro-Ecological Zones of Ghana.

Treatment	Weeks After Transplanting (WAT)							
	3	5	7	9	11	13	15	17
Agro-Eco. Zone								
Coastal-savannah (Z_1)	3.2^{a}	4.1^{a}	4.8^{a}	6.8^{a}	7.1^{a}	7.6^{a}	8.2^{a}	8.8^{a}
Forest-savannah (Z_2)	1.5^{b}	2.7^{b}	3.2^{b}	4.5^{b}	5.6^{b}	6.4^{b}	6.6^{b}	7.4^{b}
Semi deciduous (Z_3)	1.6^{b}	2.9^{b}	4.4^{a}	6.1^{a}	7.3^{a}	8.1^{a}	9.1^{c}	10.1^{c}
LSD (p = 0.05)	**0.58**	**0.54**	**0.75**	**0.88**	**0.79**	**0.80**	**0.79**	**0.87**
Cultivar								
Agyenkwa (C_1)	2.1^{a}	3.3^{a}	4.3^{a}	5.9^{a}	7.0^{a}	7.8^{a}	8.3^{a}	9.4^{a}
Asempa (C_2)	2.0^{a}	3.2^{a}	3.8^{a}	5.3^{a}	5.8^{b}	6.5^{b}	7.0^{b}	8.0^{bc}
Hougbelor (C_3)	2.2^{a}	3.4^{a}	4.4^{a}	6.3^{a}	7.4^{a}	8.1^{a}	8.5^{a}	9.3^{ac}
Y'anyawoa(C_4)	2.0^{a}	3.0^{a}	4.1^{a}	5.6^{a}	6.6^{ab}	7.2^{ab}	7.9^{ab}	8.3^{c}
LSD (p = 0.05)	**0.67**	**0.62**	**0.87**	**1.02**	**0.91**	**0.93**	**0.91**	**1.00**
Interaction effect								
Z_1C_1	3.6^{a}	4.5^{a}	5.4^{a}	7.4^{a}	7.7^{ab}	8.2^{ac}	8.7^{ae}	9.5^{ac}
Z_1C_2	2.8^{ac}	3.7^{ac}	4.0^{ac}	5.9^{abd}	6.3^{b}	6.9^{a}	7.7^{ab}	8.2^{abd}
Z_1C_3	3.7^{a}	4.7^{a}	5.4^{a}	7.4^{a}	7.9^{a}	8.3^{ac}	8.8^{ae}	9.6^{ac}
Z_1C_4	2.7^{ac}	3.4^{bc}	4.4^{ac}	6.3^{ab}	6.7^{ab}	6.9^{a}	7.5^{ab}	8.0^{abd}
Z_2C_1	1.5^{b}	2.6^{b}	3.5^{bcd}	4.7^{bc}	6.0^{b}	6.6^{ab}	7.0^{bd}	8.2^{abd}
Z_2C_2	1.5^{b}	2.8^{bc}	3.0^{bc}	4.1^{c}	4.7^{c}	5.2^{b}	5.4^{c}	6.8^{b}
Z_2C_3	1.6^{b}	2.9^{bc}	3.3^{bc}	4.7^{bc}	6.0^{b}	7.0^{a}	7.0^{bd}	7.6^{b}
Z_2C_4	1.3^{b}	2.6^{b}	3.0^{bc}	4.4^{cd}	5.9^{b}	6.8^{a}	6.8^{bd}	7.0^{b}
Z_3C_1	1.2^{b}	2.8^{bc}	4.0^{ac}	5.5^{cd}	7.3^{ab}	8.4^{ac}	9.2^{ae}	10.5^{c}
Z_3C_2	1.7^{bc}	3.2^{bc}	4.4^{ac}	5.9^{abd}	6.4^{b}	7.2^{a}	8.0^{ad}	9.0^{cd}
Z_3C_3	1.4^{b}	2.7^{bc}	4.4^{ac}	6.7^{ab}	8.2^{a}	8.9^{c}	9.8^{e}	10.6^{c}
Z_3C_4	2.1^{bc}	3.0^{bc}	4.9^{ad}	6.1^{abc}	7.3^{ab}	7.9^{ac}	9.3^{e}	10.0^{c}
LSD (p = 0.05)	**1.16**	**1.07**	**1.50**	**1.76**	**1.58**	**1.61**	**1.57**	**1.73**
CV (%)	**32.9**	**19.6**	**21.4**	**18.1**	**14.0**	**12.9**	**11.7**	**11.7**

Within column means with different superscripts differ significantly ($P < 0.05$).

Table 3
Height of Parent plant (cm) grown in three Agro-Ecological Zones of Ghana.

Treatment	Weeks After Transplanting (WAT)							
	3	5	7	9	11	13	15	17
Agro-Eco. Zone								
Coastal-savannah (Z_1)	44.23^{ab}	49.47^{a}	54.73^{a}	64.94^{a}	69.47^{a}	71.04^{a}	82.14^{a}	93.50^{a}
Forest-savannah (Z_2)	51.81^{a}	57.73^{a}	62.53^{ab}	68.34^{ab}	76.00^{ab}	90.74^{b}	100.68^{b}	106.90^{a}
Semi deciduous (Z_3)	42.44^{b}	54.60^{a}	66.03^{b}	75.28^{b}	85.00^{b}	102.74^{b}	115.52^{c}	127.30^{b}
LSD (p = 0.05)	**7.671**	**7.616**	**7.894**	**10.009**	**10.991**	**13.486**	**14.441**	**15.097**
Cultivar								
Agyenkwa (C_1)	50.16^{a}	57.11^{a}	63.86^{a}	71.99^{a}	77.91^{a}	88.03^{a}	97.91^{a}	111.18^{a}
Asempa (C_2)	45.31^{a}	52.68^{a}	61.50^{a}	72.07^{a}	78.89^{a}	87.92^{a}	99.79^{a}	108.96^{a}
Hougbelor (C_3)	47.69^{a}	55.46^{a}	62.02^{a}	69.81^{a}	77.48^{a}	90.76^{a}	102.34^{a}	110.60^{a}
Y'anyawoa(C_4)	41.48^{a}	50.48^{a}	57.01^{a}	64.21^{a}	73.02^{a}	85.99^{a}	97.74^{a}	106.21^{a}
LSD (p = 0.05)	**8.857**	**8.794**	**9.116**	**11.558**	**12.692**	**15.573**	**16.675**	**17.433**
Interaction effect								
Z_1C_1	47.90^{ab}	53.13^{ab}	61.10^{ab}	73.13^{ac}	75.47^{ab}	77.57^{abc}	89.13^{abc}	103.67^{ab}
Z_1C_2	38.27^{a}	42.57^{a}	47.23^{a}	59.67^{ab}	66.67^{ab}	68.10^{ab}	78.30^{ab}	88.87^{ab}
Z_1C_3	53.77^{b}	59.43^{b}	64.67^{b}	77.30^{ac}	79.77^{a}	81.67^{abc}	93.30^{ac}	102.87^{ab}
Z_1C_4	36.97^{a}	42.73^{a}	45.90^{a}	49.67^{b}	56.00^{b}	56.83^{a}	67.83^{b}	78.50^{a}
Z_2C_1	56.27^{b}	61.90^{b}	63.57^{b}	69.13^{ac}	75.80^{ab}	88.17^{bcd}	97.30^{ac}	105.53^{ab}
Z_2C_2	58.33^{b}	61.73^{b}	68.63^{b}	76.60^{a}	82.00^{a}	94.27^{bcd}	103.20^{acd}	107.67^{abd}
Z_2C_3	49.13^{ab}	53.57^{ab}	59.20^{ab}	62.93^{abc}	74.67^{ab}	93.30^{bcd}	104.53^{acd}	110.63^{bd}
Z_2C_4	43.50^{ab}	53.70^{ab}	58.73^{ab}	64.70^{abc}	71.53^{ab}	87.23^{bcd}	97.70^{ac}	103.73^{ab}
Z_3C_1	46.30^{ab}	56.30^{ab}	66.90^{b}	73.70^{ac}	82.47^{a}	98.35^{cd}	107.30^{cd}	124.33^{bd}
Z_3C_2	39.33^{a}	53.73^{ab}	68.63^{b}	79.93^{c}	88.00^{a}	101.40^{cd}	117.87^{cd}	130.33^{bd}
Z_3C_3	40.17^{a}	53.37^{ab}	62.20^{ab}	69.20^{abc}	78.00^{a}	97.30^{cd}	109.20^{cd}	118.30^{bd}
Z_3C_4	43.97^{ab}	55.00^{ab}	66.40^{b}	78.27^{ac}	91.53^{a}	113.90^{d}	127.70^{d}	136.40^{d}
LSD (p = 0.05)	**15.341**	**15.232**	**15.789**	**20.018**	**21.983**	**26.973**	**28.882**	**30.195**
CV (%)	**19.6**	**16.7**	**15.3**	**17.0**	**16.9**	**18.1**	**17.2**	**16.3**

Within column means with different superscripts differ significantly ($P < 0.05$).

respectively) and Hougbelor recorded the highest at the last three sampling periods (90.76, 102.34 and 110.60 cm respectively). Y'anyawoa recorded the shortest parent plants at all sampling periods.

The agro-ecological zone by cultivar interaction was significant ($P < 0.05$) for height of parent plant at all sampling periods. Asempa grown in the Forest-savannah zone produced the tallest plants (58.33 cm) at 3 WAT, Agyenkwa grown in the Forest-savannah zone produced the tallest at 5 WAT (61.90 cm), Asempa grown in either of the Forest-savannah and Semi-deciduous zones produced the tallest at 7 WAT (68.63 cm) while Asempa grown in the Semi-deciduous zone produced the tallest at the 9 WAT (79.93 cm). At the last four sampling periods, Y'anyawoa grown in the Semi-deciduous zones produced the tallest plants of 91.53 cm, 113.90 cm, 127.70 cm and 136.40 cm at 11, 13, 15 and 17 WAT respectively. The shortest plants in terms of the interaction effects were produced by Asempa grown in the Coastal-savannah zone at 5 WAT (42.57 cm) and by Y'anyawoa grown in the Coastal-savannah zone at the rest of the sampling periods (36.97 cm, 45.90 cm,).

3.2. Reproductive and yield parameters

3.2.1. Number of suckers/stand

Results on number of suckers/stand are shown in Table 4. Number of suckers/stand differed significantly ($P < 0.05$) among the agro-ecological zones at all sampling periods except at 17 WAT. The highest number of suckers/stand were recorded in the Semi-deciduous zone at all sampling periods (3.8, 7.4, 12.02 and 19.20 at 11, 13, 15 and 17 WAT respectively) while the lowest was recorded in the Forest-savannah zone (2.1, 4.4, 6.57 and 14.2 at 11, 13, 15 and 17 WAT respectively).

There were no significant ($P > 0.05$) differences among the cultivars for number of suckers/stand at all sampling periods. The Agyenkwa cultivar produced slightly more suckers/stand than all the other cultivars at 11, 13, 15 and 17 WAT.

Interacting Agro-ecological zone with cultivar resulted in significant ($P < 0.05$) differences for number of suckers/stand at all sampling periods except at 3 WAT where no significant ($P > 0.05$) interaction was observed. At 3 WAT, the highest number of suckers/stand resulted from Hougbelor grown in the Semi-deciduous zone, from Agyenkwa grown in the Coastal-savannah at 5 and 7 WAT and from Agyenkwa grown in the Semi-deciduous zone at the 9 WAT.

3.2.2. Number of inflorescence/stand

Results on number of inflorescences/stand are shown in Table 5. Number of inflorescence/stand differed significantly ($P < 0.05$) among the agro-ecological zones, cultivars as well as their interactions. The Coastal-savannah zone and the Semi-deciduous zone differed significantly ($P < 0.05$) but were at par with the Forest-savannah zone. The Coastal-savannah zone recorded the highest number of inflorescences/stand of 1.17 whilst the Semi-deciduous zone recorded the least (0.25).

The Agyenkwa and Asempa cultivars were at par but differed significantly ($P < 0.05$) from the rest of the cultivars which were however statistically similar ($P > 0.05$). Agyenkwa produced slightly more inflorescence/stand (1.51) than Asempa (1.38) while Hougbelor and Y'anyawoa produced no inflorescence.

Table 4
Number of suckers produced/stand by taro grown in three Agro-Ecological Zones of Ghana.

Treatment	Weeks After Transplanting (WAT)			
	11	13	15	17
Agro-Eco. Zone				
Coastal-savannah (Z_1)	2.3^a	6.5^{ab}	11.84^a	19.1^a
Forest-savannah (Z_2)	2.1^a	4.4^a	6.57^b	14.2^a
Semi deciduous (Z_3)	3.8^b	7.4^b	12.02^a	19.2^a
LSD (p = 0.05)	**1.54**	**2.43**	**3.52**	**6.32**
Cultivar				
Agyenkwa (C_1)	2.9^a	6.8^a	12.0^a	21.4^a
Asempa (C_2)	2.5^a	5.5^a	8.6^a	14.7^a
Hougbelor (C_3)	2.7^a	6.2^a	10.3^a	17.5^a
Y'anyawoa(C_4)	2.7^a	5.9^a	9.7^a	16.4^a
LSD (p = 0.05)	**1.78**	**2.81**	**4.07**	**7.29**
Interaction effect				
Z_1C_1	4.1^a	9.6^a	14.2^{ac}	25.0^a
Z_1C_2	1.5^a	3.9^b	7.7^{ab}	11.7^b
Z_1C_3	1.6^a	6.3^{ab}	14.4^{ac}	23.2^{ab}
Z_1C_4	2.0^a	6.4^{ab}	11.1^{abc}	16.7^{ab}
Z_2C_1	1.9^a	3.8^b	6.9^b	18.1^{ab}
Z_2C_2	1.8^a	3.3^b	5.4^b	11.1^b
Z_2C_3	1.9^a	5.1^{ab}	6.6^b	11.8^b
Z_2C_4	2.7^a	5.4^{ab}	7.5^{ab}	15.8^{ab}
Z_3C_1	2.6^a	6.9^{ab}	14.8^c	21.1^{ab}
Z_3C_2	4.3^a	9.4^a	12.7^{abc}	21.4^{ab}
Z_3C_3	4.7^a	7.1^{ab}	10.0^{abc}	17.5^{ab}
Z_3C_4	3.5^a	5.9^{ab}	10.6^{abc}	16.8^{ab}
LSD (p = 0.05)	**3.08**	**4.86**	**7.05**	**12.63**
CV (%)	**67.1**	**47.1**	**41.0**	**42.6**

Within column means with different superscripts differ significantly ($P < 0.05$).

Table 5
Reproductive and yield parameters of taro grown in three Agro-Ecological Zones of Ghana.

Treatment	Number of inflorescence/stand	Corm weight/ Plot (kg)	Total corm yield (tons/ha)
Agro-Eco. Zone			
Coastal-savannah (Z_1)	1.17^a	1.96^a	19.62^a
Forest-savannah (Z_2)	0.75^{ab}	1.82^a	18.17^a
Semi deciduous (Z_3)	0.25^b	1.80^a	18.00^a
LSD (p = 0.05)	**0.837**	**0.602**	**6.019**
Cultivar			
Agyenkwa (C_1)	$\mathbf{1.51^a}$	1.53^a	15.33^a
Asempa (C_2)	1.38^a	1.42^a	14.22^a
Hougbelor (C_3)	0.00^b	$\mathbf{2.36^b}$	$\mathbf{23.56^b}$
Y'anya woa (C_4)	0.00^b	2.13^b	21.28^b
LSD (p = 0.05)	**0.967**	**0.579**	**5.790**
Interaction effect			
Z_1C_1	2.43^a	2.10^{ac}	21.00^{ac}
Z_1C_2	2.23^a	1.00^b	10.00^b
Z_1C_3	0.00^b	2.57^a	25.67^c
Z_1C_4	0.00^b	2.25^{ac}	22.50^{ac}
Z_2C_1	1.10^a	1.47^{bc}	14.67^{ab}
Z_2C_2	1.90^a	1.63^{bc}	16.33^{abc}
Z_2C_3	0.00^b	2.00^{ac}	20.00^{ac}
Z_2C_4	0.00^b	2.17^{ac}	21.67^{ac}
Z_3C_1	1.00^a	1.03^b	10.33^b
Z_3C_2	0.00^b	1.63^{bc}	16.33^{abc}
Z_3C_3	0.00^b	2.50^a	25.00^c
Z_3C_4	0.00^b	1.97^{abc}	19.67^{abc}
LSD (p = 0.05)	**1.675**	**0.997**	**9.966**
CV (%)	**136.9**	**31.6**	**31.6**

Within column means with different superscripts differ significantly ($P < 0.05$).

Growing Agyenkwa in the Coastal-savannah zone resulted in the highest interaction of 2.43, followed by Asempa grown in the Forest-savannah zone (2.23) and the lowest of 1.00 was recorded by Agyenkwa grown in the Semi-deciduous zone. Growing the Hougbelor and Y'anyawoa in either of the agro-ecological zones resulted in no inflorescence production.

3.2.3. Corm weight/plot and total corm yield

Results for corm weight/plot and corm yield/ha are also presented in Table 5. No significant ($P > 0.05$) differences were observed among the agro-ecological zones for corm weight/plot and total corm yield/ha. Agyenkwa and Asempa were statistically similar but both differed significantly ($P < 0.05$) from Y'anyan woa and Hougbelor in terms of corm weight/plot and corm yield/ha. Meanwhile, Y'anyan woa and Hougbelor were also statistically similar. However, significant ($P < 0.05$) cultivar*agro-ecological zone interactions were recorded for corm weight/plot and yield/ha.

Among the agro-ecological zones, the Coastal savannah zone contributed greatest to corm weight/plot and yield/ha (1.96 kg and 19.62 tons/ha respectively) whilst the Hougbelor cultivar produced the highest corm weight/plot and yield/ha of 2.36 kg and 23.56 tons/ha, followed by Y'anyawoa which produced 2.13 kg and 21.28 tons/ha corm weight/plot and yield/ha respectively. Meanwhile, the lowest corm weight/plot and yield/ha of 1.42 kg and 14.22 tons/ha respectively were produced by the Asempa cultivar. Interactively, the highest corm weight/plot and yield/ha of 2.57 kg and 25.67 tons/ha respectively were produced by the Hougbelor cultivar grown in the Coastal-savannah zone while the lowest corm weight/plot of 1.00 kg which translated into 10.00 tons/ha resulted from Asempa cultivated in the Coastal-savannah zone.

4. Discussion

4.1. Effects of agro-ecological zones and cultivar on the growth of taro

Significant differences among the agro-ecological zones in terms of the vegetative growth of taro during most of the sampling periods indicate unique environmental conditions prevalent in the agro-ecological zones. The environment had a variety of effects on the cultivars due to the varied climatic conditions that occurred at the research locations during the study period. This discovery is in agreement with other researchers [22,23], and [24], who found significant differences between environments in multi-environment trials. According to Paul et al. [25], tall plants may be attributed to genetic traits. This is likely due to the fact that genotype's performance in different environments can be a significant limitation in genotype breeding and selection for narrow and wide adoptions [26]. However, the significantly tall plants resulting from the semi-deciduous zone is due to favourable climatic conditions such as rain.

The study showed that the Coastal-savannah and Semi-deciduous forest zones enhanced leaf production which was however made manifest upon cultivating Hougbelor. Tall plants result from longer petioles. The Semi-deciduous forest zone mostly produced the tallest taro plants and was mostly manifested in the Y'anyawoa cultivar. Similar results on genetic differences among crops producing characters like plant height were also advanced earlier in peanut [27] and in rice [28]. However, leaf production may to the highest extent be a combined effect from soil nutrient levels and climatic factors such as rainfall. Similarly, Garba et al. [28] reported that growth and development in rice for instance depend partly on environmental factors, especially radiation, temperature and nutritional conditions. Seaton et al. [27] also indicated that the Semi-deciduous forest zone of Ghana is characterized by adequate rainfall for the cultivation of large scale plantation and annual crops. The zone also contains most of the productive soils of the country [29].

4.2. Effects of agro-ecological zones and cultivar on reproduction and yield of taro

Growing taro in the Semi-deciduous forest zone resulted in the highest number of suckers with the Agyenkwa cultivar being the best. A survey study [30] on the causes and suggested remedies to taro endangerment in the Western, Bono, Ashanti and Eastern Regions of Ghana, revealed that declined cultivation of the crop is as a result of unavailability of planting materials which corroborates with the report at the FAO Database [31]. Though suckers left on the field after harvest can develop into edible corms, they can also be retained in nurseries to develop excellent sprouts, especially if there is a considerable period between harvest and the next planting. Increasing number of suckers in this study may be due to a greater number of assimilates available in the soil and the availability of more nutrients and moisture [17].

Flowering was observed in the Agyenkwa and Asempa with Agyenkwa producing the highest number of inflorescence/stand in the Coastal-savannah zone. According to Ivancic*et al.* [32], taro is characterized by rare and erratic flowering. Many clones of taro do not flower naturally. In other clones, natural flowering is sporadic and not predictable enough for breeding [8]. Taro requires an ideal atmosphere for normal flowering and seed set. Plants do not flower or produce sterile inflorescence in instances of strong rainfall or prolonged wet weather, as well as considerable variations in ambient air temperatures [33]. The uni-modal rainfall pattern in the Coastal-savannah could probably be the reason behind the increased flowering of taro in the zone.

The significant difference among the cultivars in terms of yield indicates that the cultivars had greater genetic influences, which surpassed the effects of the conditions prevalent in the agro-ecological zones. This finding is in line with prior research, which found significant variability in maize plant development across genotypes [34,35]. The highest corm weight/plot and yield/ha, resulted from the Coastal savannah zone with Hougbelor producing the highest among the cultivars may be due to the high growth response of the cultivar. These results coincide with a report by Mabhaudhi and Modi [15] that taro cultivation in South Africa is concentrated along the coastal areas with the perception that taro is 'water loving'. In addition, the high corm yield recorded from the Coastal-savannah zone may be in accordance with the high number of suckers recorded from the zone, some of which developed into edible corm, thereby increasing corm yield.

5. Conclusion

The study revealed that taro is generally adapted to the Coastal-savannah zone for translating the high vegetative growth into edible leaf and corm. Hence, the Coastal-savannah zone is most appropriate for commercial taro production in Ghana. The Hougbelor cultivar yielded more leaves and corms for consumption, whilst the Agyenkwa cultivar produced higher number of planting materials in the form of suckers and inflorescence which could stay viable for longer periods when best managed. A taro breeding programme targeting the combination of the high yielding and reproductive potentials of Hougbelor and Agyenkwa cultivars respectively, is necessary to increase taro production, and lead to increased utilization in Ghana.

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CRediT authorship contribution statement

Emmanuel Oduro: Conceptualization, Methodology, Writing – original draft. **Esther Fobi Donkor:** Writing – review & editing. **Emmanuel Ackah:** Data curation, Visualization. **Kwadwo Gyasi Santo:** Writing – review & editing.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Data availability

Data will be made available on request.

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